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Abstract
Throughout the Cornbelt eco-region, nitratenitrogen (NO3-N) is the most frequent pollutant exceeding the U.S. Environmental Protection Agency's maximum contaminant limits for municipal drinking water supplies. Agricultural fertilizers that leach or run off from row-cropped fields are the principal source of NO3-N. This potential contamination poses a health concern that is attracting increasing attention among the urban and rural populace alike.

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Agroforestry, Conservation practices, Water quality quantity and management

Disciplines
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Poplar tree buffer strips grown in riparian corridors for non-point source pollution control and biomass production

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Budget
$39,517 for year one
$19,405 for year two
$35,000 for year three
$35,000 for year four

Background and goals

Throughout the Cornbelt eco-region, nitrate-nitrogen (NO_3-N) is the most frequent pollutant exceeding the U.S. Environmental Protection Agency's maximum contaminant limits for municipal drinking water supplies. Agricultural fertilizers that leach or run off from row-cropped fields are the principal source of NO_3-N. This potential contamination poses a health concern that is attracting increasing attention among the urban and rural populace alike.

Tree buffer strips, specifically perennial poplar buffers located strategically along such fields, can serve a dual purpose by removing the nitrate from near-surface groundwater *and* by producing a new commodity—woody biomass. Data have shown that NO_3-N levels are reduced well below 10 parts per million in soils that are tree rooted; NO_3-N is either converted to protein in the leaves and the woody stems or denitrified by soil bacteria that feed on organic carbon from the roots.

Poplar trees' physiological attributes—namely, fast growth, even in dense plantings; cut-stem rooting; resprouting from stumps; and high protein content in the leaves—contribute to a harvested value that can "pay its way" while improving water quality. Poplars are also easily cloned from stem cuttings, permitting duplication of desirable traits in a large acreage of trees, and they are capable of surviving root and stem submergence during periods of flooding. In addition to these benefits, poplar tree buffers serve as wildlife habitat, wind shelter belts, sediment traps, and sinks for chemicals such as atrazine.

Investigators in this project set two goals: (1) to grow a valuable, perennial poplar tree crop that is economically competitive with current commodity crops, and (2) to reduce negative ecological impacts from tilled land by intercepting non-point source nitrate and silt that pass through the riparian corridor and enter surface water resources.

Their objectives included

1. developing an innovative technique for growing deep root systems from poplar cuttings planted at one- and five-foot depths in alluvial soils;
2. monitoring the dispersion and concentration of NO_3-N at selected depths in the buffer strip's soil profile;
3. monitoring and measuring a short-rotation, intensive-culture biomass crop grown in buffer strips between creeks and adjacent cropped fields; and
4. quantifying the influence of deep root systems on nitrate uptake rates, evapotranspiration, and tree growth.

Approach and methods

Figure 1 shows the tree buffer concept as the investigators originally envisioned it. This study assumed

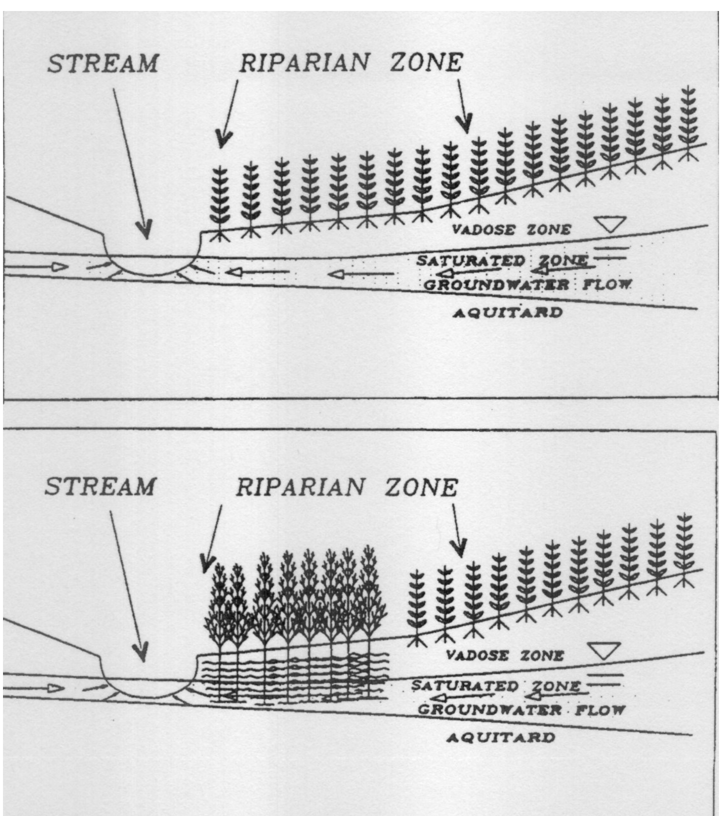
- that trees can be planted strategically as a row crop in buffers to maximize their "edge effect" benefits (the advantage that trees have along the edges of strips because of extra sunlight) and in densities designed to produce quick perennial biomass growth and canopy within two growing seasons.
- that perennial roots, when grown intentionally deep enough to intersect the near-surface water table, can reduce non-point

source NO_3-N migrating from row-cropped fields by over 90 percent;

- that harvest schedules can be designed to maintain the NO_3 removal by the root system, without the need for tillage or replanting, due to the regrowth ability of these perennial plants following cutting to stumps (coppicing); and
- that buffer regrowth from the stump following harvest is physiologically possible; managed, coppiced regrowth will reduce the need for annual tillage.

Slightly modified row-crop, farmer-owned equipment was used to mechanize field operations for the buffer installation and maintenance. This equipment can plant 1200 trees per hour with two operators using a 40-horsepower tractor. The first buffer strip was installed in spring 1988 at the Amana Society Farms, Amana, Iowa. The site contained a first-order perennial stream with annual crops planted up to the creek bank edge. Crops bordering the tree buffer strip included oats in 1988, corn in 1989 through 1991, and soybeans in 1992. Ammonia fertilizer was applied at the rate of 150 pounds (lb) N/acre in spring 1989 through 1991 to corn planted upgrade from the buffer.

Fig. 1. Top diagram shows a conventionally row-cropped riparian zone; bottom diagram shows the growing prototype, deep-rooted tree buffer.



The buffer strip paralleled the creek; it consisted often adjoining plots each 3 meters (m) by 12 m (10 feet [ft] by 40 ft). The buffer strip of trees consisted of four rows with an overall width of 3.6 m. In contrast to "normal" hardwood tree spacing that allows between 40 and 100 square ft per tree, these poplars were spaced 1 ft apart in the row and 40 inches (in.) between rows for an area allocation of 3.3 sq ft per tree in the buffer strip. A 15-ft-wide fallow strip adjacent to the creek was included as a drive for equipment. The total tree buffer and fallow strip was 0.24 acre.

The entire area was tilled to a 6-in. depth to break up topsoil and remove surface vegetation. One plot was planted with 172 poplar cuttings 5.5 ft long; they were vertically inserted into 5-ft-deep trenches dug parallel to the creek by a Ditch Witch® trencher. Other plots were planted with 1-ft-long cuttings manually inserted 10 in. deep at the same population density. No fertilizers or herbicides have been applied to the trees since the buffer installation.

Piezometers were installed 5 ft below the soil surface in transects located 7 ft upgrade from the tree buffer, at midplot, and at 7 ft downgrade. Water samples from the piezometers were obtained by using a peristaltic pump. These wells were normally sampled on a weekly basis during the growing season. Workers obtained soil samples by excavating with a backhoe to desired depths in 1988 through 1990 or by performing corings with a sampling machine.

Findings

In 1988, Iowa had its worst drought in recorded history; the site received no significant rainfall until September. Survival data collected in November, at the end of the first growing season, showed that for plots 2,4, and 5 of the 1-ft cuttings, the survival was 37%, 39%, and 50% respectively. The 5-ft-deep plot with a population of 172 cuttings had only one tree death for a 99.4% survival rate during the severe drought conditions. Cuttings 5.5 ft long planted 5 ft deep in the riparian soils had a significantly higher survival rate than the 1-ft cuttings planted 10 in. deep.

For the first 5-ft-deep cuttings, survival between rows did not differ significantly; for the 1-ft cutting plot, it did. In all 1-ft cutting plots, no trees survived in the row located adjacent to the growing oat crop, apparently because of an inability to compete with oats for limited water. Since establishment, trees have been pruned, coppiced, and harvested to measure biomass weights. No trees have died or will be harvested in the surviving row adjacent to the up-gradient crop. As this work continues, these trees will be used to estimate the growth and N uptake rates for the five-year old poplars.

Backhoe excavation in 1988, 1989, and 1990 allowed direct observation and sampling of roots that developed from the entire buried cutting length when 5.5-ft cuttings were planted to depths of 5 ft in field plots. For 1-ft cuttings, roots grew primarily within the top 18 in. of soil, though several thin roots grew down 6 ft into the soil and to the normal water table elevation. The 5.5-ft cuttings averaged 20 primary lateral roots with secondary roots at depths of 4 to 5 ft.

This in-field rooting success corroborates greenhouse experiment results. The greenhouse test also investigated poplar's resilience to submersion; it showed that roots grow most vigorously in a zone 8 in. above and below the water table. *The presence of living roots in the entire submerged cutting depth is critical to the removal of nitrate from near-surface groundwater.*

Establishing a poplar buffer using the deep-planting technique significantly reduces nitrate concentrations in the soil profile. For the newly planted buffer, investigators sampled average NO_3-N in the top 4 ft of soils at 1-ft increments. In October 1989, the NO_3-N means in the soils sampled averaged a constant 2 to 3 milligrams (mg) N per kilogram (kg) of dry soil. The nitrate concentration profile for the 5.5 ft cutting plot was significantly different from all other plots.

There was no significant difference in the nitrate concentration profiles between the fallow and 1-ft cutting plots following the first two growing seasons. Concentrations below corn in the soil profile show values ranging from 10 to 35 mg/kg NO_3-N in the top 4 ft. Investigators attributed significant variation from this range in the 1989 data to poor plant growth due to the previous season's drought. A significant difference between the corn nitrate profile and all other plot treatments was attributed to the addition of 150 lb NH_3-N (anhydrous ammonia) fertilizer to the cropped soil in March 1989. The tree roots took up nitrate along the entire buried cutting depth; the piezometer samples corroborated this finding.

Plot well measurements showed that poplar tree roots also reduce $N0_3$-N in near-surface groundwater. Following heavy September rains in the second growing season, sampled wells 20 ft apart beneath the corn and the poplar buffer contained 92 mg nitrate per liter and 2 mg nitrate per liter, respectively. *Continuous summer monitoring of the buffers has consistently shown a near-complete removal of nitrate from this groundwater in all seasons by the tree buffer.*

Trees spaced 1 ft apart and 40 in. between rows for 3.3 sq ft per tree had a population of 13,200 trees per acre. After two growing seasons, the sampled trees were over 15 ft tall. Growth rates averaged 5.4 grams (0.011 lb) of biomass per tree per day on a dry weight basis during their second six-month growing season. At this rate, the poplar buffer strip will yield more than 20,000 lb wood dry matter, per acre, per year, starting in the third growing season. Investigators found no significant difference in the growth rates between deep and shallow rooted poplars following the first growing season.

The sampled poplar trees contained an average of 2.3% N in the leaf tissue and 0.1 to 0.4% N in the stem. This plant N, in the form of protein, amino acids, and other organic molecules, was all metabolized from inorganic nitrate or ammonium N taken up by the roots from the soil pore water. In 1989, each tree removed an estimated N mass of 10 grams per tree during the six-month growing season for an average uptake of 57 mg/tree/day. At this rate, the harvested stem and leaf in the buffer strip poplars contained an estimated 300 lb N/acre in two growing seasons. The leaf/stem ratio and the N content in the stem and leaf suggest the need for some type of leaf management, such as total plant removal, fallen leaf removal, or leaf grazing by livestock.

Implications

This project challenged the assumption that row-crop tillage in the riparian corridor is the highest and best land use, and it tested the innovative concept that roots from selected tree species can be intentionally grown to depths that intersect the near-surface water table.

It has also clearly demonstrated that poplar trees offer potential for reducing the negative water quality impacts resulting from N use in modern Cornbelt agriculture. The poplar tree buffer works to consistently remove about 95% of the NO_3-N leaking from annual row-cropped fields in the near-surface groundwater. This wood is becoming a valuable commodity crop in some areas of the world. The buffers grew over 20,000 lb of wood dry matter per acre per year starting in their third growing season. This growth rate—assuming 8000 BTU/lb of wood and 134,000 BTU/gallon of fuel oil—can yield energy equivalent to 1000 gallons of fuel oil per acre per year.

Related research involves burning poplar-derived fuel in furnaces and wood stoves using burner designs that minimize air pollutant emissions; these data are being combined with the water quality data collected from this project to help determine overall nitrogen and carbon budgets when field edges are cropped using this technique. Most importantly, however, the poplar tree buffer strip concept is feasible, practical, and safe for use *now*.

The technique emerging from this project, named the Ecolotree Buffer, has also shown promise as a Best Management Practice to reduce agricultural non-point pollution of water supplies. The data gathered in this project have been instrumental in the development of a paired-watershed research site, operated by the University of Iowa at Amana, Iowa, to compare the quality and quantity of surface water from alternative cropping and buffering schemes.

Finally, this project included a significant education and outreach component. As a result, farmers are now trying the buffer concept in their own fields in Iowa as well as other states. Tour audiences have included elementary and secondary students, state agency engineers, university faculty, college classes, international dignitaries, farmers, and garden clubs; the project was also presented at the 1991 Farm Progress Show. A variety of state and federal agencies have combined resources to study the efficacy of these buffers as a prime way to farm the edges and margins of Iowa farm land.

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